Translation of article 10.22146/jnteti.v13i1.8564

Monitoring and Controlling of IoT-Based Greenhouse Parameters With the MQTT Protocol

Eni Dwi Wardihani[1], Eka Ulia Sari[1], Helmy[1], Ari Sriyanto Nugroho[1], Yusnan Badruzzaman[1], Arif Nursyahid[1], Thomas Agung Setyawan[1], Media Fitri Isma Nugraha[2]

[1] Program Studi Teknik Telekomunikasi, Jurusan Teknik Elektro, Politeknik Negeri Semarang, Semarang, Indonesia
[2] National Research and Innovation Agency, Jakarta, Indonesia

[Submitted: 1 August 2023, Revised: 29 September 2023, Accepted: 13 December 2023]
Corresponding Author: Helmy (email: helmy@polines.ac.id)

ABSTRACT — Modernization in the agricultural sector is expected to have an effect on improving the quality, production quantity, and continuity of the agricultural product supply. Currently, many smart agricultures are developed in greenhouses. However, several greenhouse parameters must be considered to optimize plant growth. This study has created a monitoring and control system for several Internet of things (IoT)-based greenhouse parameters, allowing farmers to monitor and control the greenhouse anytime and anywhere. It can also improve the work efficiency of farmers in monitoring and controlling, especially if there are multiple greenhouses to be monitored or controlled. The greenhouse monitoring data may be viewed in real time and stored on servers, making it easier for farmers to evaluate greenhouses and crops. The monitored parameters were greenhouse temperature, greenhouse humidity, and light intensity in the greenhouse, while the controlled parameters were greenhouse temperature and greenhouse humidity, using exhaust fans. The process of transmitting the greenhouse parameter monitoring and controlling data was carried out using the message queue telemetry transport (MQTT) protocol. Data loss and delay testing on the system was required to determine the reliability of the tool in the process of transmitting and receiving data. The quality of service (QoS) testing results was as follows: average data loss gateway-server monitoring was 10.6%, the average gateway-server monitoring delay was 1.9 s, and the average server-gateway control delay was 7.1 s. When the greenhouse temperature parameter value is less than the specified maximum threshold, the system turns on the drum fan so that the temperature reaches the minimum value at the threshold limit.

KEYWORDS — MQTT, IoT, Greenhouse, QoS.

I. INTRODUCTION

With the onset of the free market and globalization, the flow of goods, including agricultural products like staple foodstuffs, will become more unrestricted and accessible within Indonesia’s borders. It poses an important threat to local farmers and could lead to a reliance on imported food products [1]. The government has taken several steps to anticipate the effects of globalization, one of which is the efficiency of agricultural businesses through agricultural modernization by utilizing modern agricultural technology 4.0. This modernization is expected to improve the quality, quantity, and continuity of food supply, thereby enabling the attainment of national food security [1]. One of the focuses of food security policy is to enhance food production capacity by promoting innovation with the involvement of the private sector through research and development in agriculture and facilitating the import of modern agricultural technology [2].

Smart agriculture is currently being developed in greenhouses to achieve food security. It allows farmers to set the parameters needed for plants to grow optimally and be more efficient in their management [3]. One example of intelligent agriculture implementation is the Internet of things (IoT)-based nutrient film technique (NFT) type hydroponic cultivation system. NFT-type hydroponics is a hydroponic system that utilizes the slope of the channel in the flow of water containing nutrients for plants. The NFT system is designed using a water channel with the right slope, length, and water flow rate [4]. The advantage of the NFT system is that the plant’s roots are exposed to sufficient nutrients, oxygen, and water. This system saves water use because the water layer flowing in this system is very thin, resembling a film with thickness of 3 mm [5]. In addition, the volume of required nutrient solution is lower than in other water cultures, the temperature around plant roots is easier to regulate, pests and diseases are easier to control, plant density per unit area is higher, and crop yields are cleaner because there is no soil residue or other media [6]. On the other hand, the disadvantage of the NFT system is its dependence on the water pump because it must continue to run during the growth process [7].

The utilization of modern technology, which enables devices like smartphones to be employed to control any object manually or automatically, presents an opportunity to implement wireless control in agricultural systems, encompassing both conventional agriculture (soil media) and hydroponic agriculture [8]. In IoT technology, all activities carried out by humans can be controlled through the Internet network. The role of IoT in the cultivation of NFT greenhouse is very helpful in easing farmers’ work, especially for greenhouse control, without spending a lot of energy. The application of IoT technology can help the system appropriately provide nutrients to hydroponic plants in accordance with the specified time, send accurate and real-time data via the Internet, and display it on web applications that may be accessed from anywhere [9]. Not only that, this IoT-based greenhouse monitoring and control system is also useful for urban communities. People in urban areas who want to implement hydroponic methods in farming have obstacles in controlling and monitoring plant conditions. People living in cities often have busy schedules, leaving them with little time to observe the progress of hydroponic plants directly [5].

The implementation of IoT allows farmers to monitor and control the parameters of hydroponic systems anytime and anywhere. Environmental parameters greatly affect the growth and development of plants and the success of hydroponic systems [10]. Periodic monitoring of parameters and adjustment to normal or ideal conditions will contribute to the harvest's success. The supporting parameters of harvest success are temperature, humidity, and light intensity. The ideal temperature for the hydroponic cultivation method is around 25–28 °C [11], while the ideal light intensity ranges from 2,000–3,000 fc. The extent of the greenhouse and the farmers' limitations in monitoring it at all times are one of the obstacles to the success of the harvest. Monitoring performed manually by farmers using measuring instruments is highly ineffective. In addition, it is very time-consuming and energy-consuming for farmers if there is more than one greenhouse that needs to be monitored. The addition of automation devices is expected to reduce the amount of time farmers take care of crops directly and to reduce concerns when farmers are away for extended periods [3].

Several studies on IoT-based monitoring have been conducted before. A study monitored environmental conditions with a multi-hop wireless sensor network system using the NodeMCU IoT platform with an ESP8266 Wi-Fi module. The employed topology was bus and tree [12]. Another study has designed a prototype of a water and agricultural soil quality monitoring system using the Arduino Uno as a microcontroller and the ESP8266 module as a sensor node link to the network. The data exchange between sensor nodes was conducted using a peer-to-peer system [13]. Soil condition monitoring using wireless sensor networks (WSN) and IoT-based sensors has also been carried out. The monitored parameters were soil temperature and humidity, while the controlled parameters were water level and temperature [14]. Room temperature and humidity monitoring were carried out using SHT11 sensors and lab-scale CM5000 node microcontrollers. Moisture values read in analog form were converted to real humidity in percentage form [15].

According to previous studies, it is known that they only monitored and controlled one greenhouse and did not include delay testing, data loss, and receive signal strength indicator (RSSI). Farmers may also monitor and control anytime and anywhere using the app. The employed data transmission system is a star (point-to-point) topology with an IoT-based message queue telemetry transport (MQTT) protocol. Farmers may monitor greenhouse parameters, such as light intensity, temperature, and humidity, and control the greenhouse temperature using a drum fan.

This paper is organized into four sections. Part I contains an introduction, while Part II discusses the design of IoT greenhouses. The results and discussion are detailed in Section III, while the final section, Section IV, presents the conclusions.

II. IOT DESIGN OF THE GREENHOUSE

The greenhouse monitoring and control system consists of two panels, namely nodes and gateways. There are two greenhouses located in front and behind, as well as IoT panels and contractor panels. The IoT and contractor panels are located between greenhouse 1 and 2.

In greenhouse 1 and greenhouse 2, there are only six large blowers. With certain calculations, the nodes are dispersed across greenhouse 1 (seven nodes) and greenhouse 2 (seven nodes). When the nodes are positioned too closely together, the sensor calculations yield identical results; as a result, it is considered less effective. Inside the node are two sensors: a temperature sensor, which also serves as a humidity sensor, and a light sensor.

A. MONITORING SYSTEM DESIGN

The monitored parameters in this monitoring system are temperature, humidity, and light intensity in the greenhouse. Temperature and humidity sensors are used to measure the temperature and humidity in the greenhouse, while light sensors will measure the intensity of light entering the greenhouse. The controlled parameter is the humidity of the greenhouse room.

There are two greenhouses where several nodes are dispersed in several corners of the greenhouse. The number of nodes dispersed in the two greenhouses is 14 nodes. Seven nodes are in greenhouse 1, and other seven are in greenhouse 2. Within a single node is a Wemos D1 microcontroller, a temperature and humidity sensor, and a light sensor. These nodes will measure the greenhouse's temperature, humidity, and light intensity at different corners. As the number of dispersed nodes increases, so does the accuracy value of the parameters. The parameters are transmitted to the IoT panel over a 2.4 GHz Wi-Fi network. Figure 1 illustrates the architecture of the designed monitoring system.

The IoT panel is used to display the greenhouse monitoring parameter data on the LCD panel and to display the time. On the IoT panel, there is an ESP32 SIM800L microcontroller to receive data from sensor nodes. Settings may be done directly through the IoT panel or through Android and web-based applications. The greenhouse parameter monitoring data are sent to the omahiot.net server, which is a privately owned server. The data received by the server may be accessed by the manager through the website and Android-based application. Meanwhile, the contractor panel is used to place the solid-state relay for the greenhouse control system.

There are two panels, namely the node panel and the gateway panel. The node panel consists of a Wemos D1 microcontroller connected with the SHT10 sensor and BH1750 sensor. The gateway panel includes an ESP32 SIM800L microcontroller, which is connected to an LCD and real-time clock (RTC) viewer. The Wemos D1 and ESP32 SIM800L were connected using 2.4 GHz Wi-Fi. Sensor data transmission was carried out using the MQTT protocol, while data storage was carried out using a virtual private server (VPS), i.e., omahiot.net.

The monitoring system on the gateway started with ESP32 SIM800L GPRS connected to the internet. After that, ESP32 SIM800L received data from the sensor node. The data received by the gateway device was then sent to the VPS server (omahiot.net) using MQTT. The received data were also averaged to be displayed on the LCD. These data include the greenhouse room's temperature, humidity, and light intensity. Node device is a hardware device designed to read air humidity, temperature, and light intensity and transmit sensor reading data in the greenhouse to IoT gateways/panels.

B. CONTROL SYSTEM DESIGN

The control system architecture is shown in Figure 2. The control process was carried out if the air temperature in the greenhouse was less than the minimum threshold limit, which was 16 °C.

When the measured temperature of the greenhouse is above the maximum threshold, the system activates the relay

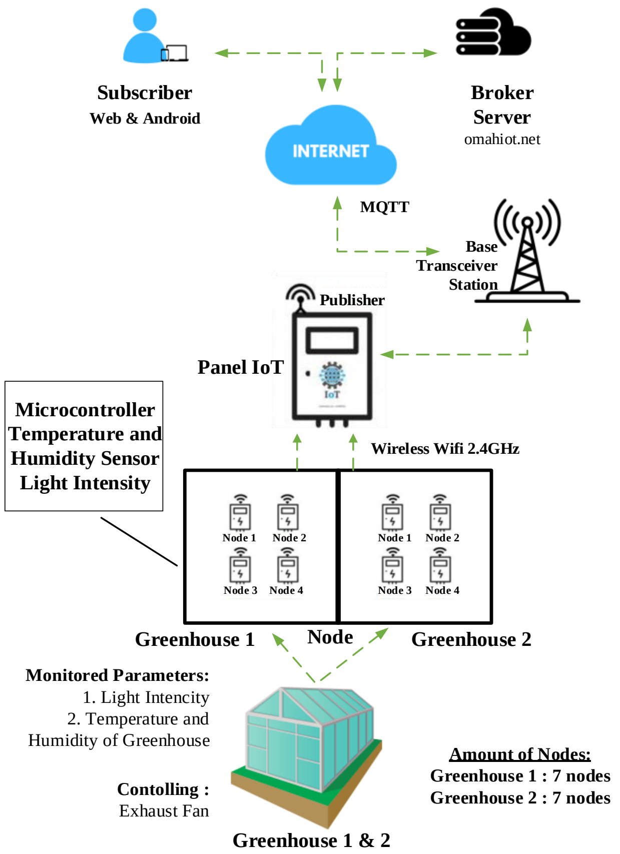

Figure 1. Monitoring system architecture.

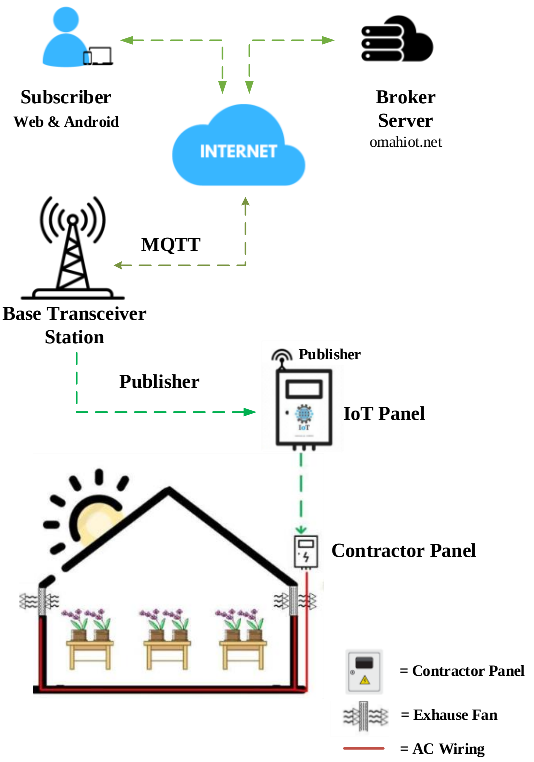

Figure 2. Control system architecture.

connected to the drum fan. The server will send temperature and humidity monitoring data to IoT panels in greenhouse 1 and 2. The IoT panels in both greenhouses will process the data and give commands to the drum fans. Then, the drum fan in both greenhouses will execute the command so that it lights up and sucks air from the inside of the greenhouse to the outside. The temperature control system is carried out to maintain a balanced temperature in the greenhouse, ensuring it remains within the optimal range. When the user sets the threshold value, ESP32 SIM800L retrieves the threshold value on the server. Once the threshold value is received, ESP32 SIM800L compares the reading value of the temperature sensor with the threshold value. If the temperature value is less than the threshold, ESP32 SIM800L will send a command to the relay to turn on the contactor panel [16]. The threshold value has a minimum and maximum value. The minimum value represents a threshold lower than the greenhouse temperature, while the maximum value represents a threshold higher than the greenhouse temperature. The drum fan is designed to activate once the temperature reaches the designated minimum threshold, and it will automatically deactivate once the threshold reaches the specified maximum value.

The control system in the gateway device starts with ESP32 SIM800L GPRS connected to the Internet. Then, the gateway device retrieves data from the server, in JSON format [17]. After successfully retrieving the data, the gateway device will compare the required data, namely the temperature threshold data with the greenhouse temperature. If the data are not retrieved successfully, the data retrieval process will be repeated. Based on the comparison results, when the greenhouse temperature falls below the specified limit, the gateway device sends a command to the contactor panel, triggering the activation of the drum fan. Conversely, when the temperature inside the greenhouse exceeds the specified threshold, it indicates that the process has been successfully completed.

C. TEST DESIGN

A test is conducted to evaluate the system's performance, determining whether it has operated effectively or not. It is carried out on the monitoring and control systems [18]. Monitoring system testing in MQTT in the form of quality of service (QoS) including delay and data loss testing to determine the tools' reliability. In contrast, control system testing includes delay testing from the server to the gateway.

1) TESTING OF MONITORING SYSTEM DELAY

This delay test was carried out by referring to the RTC. Delay calculation is obtained from the difference between the time the data is received and the time a device sends the data. Delay testing is carried out to evaluate the time taken by the tool in using MQTT to send and receive data. The 1999–2006 ETSI standard is used as a reference for system evaluation [19]. This monitoring delay test was carried out from the gateway to the server.

2) TESTING OF DATA LOSS MONITORING SYSTEM

Testing of the data loss monitoring system using MQTT was carried out at the time of transmission from the gateway to the server. The data loss tested is the data that will be sent to the server from the node. These data include soil moisture data, greenhouse temperature and humidity, and light intensity.

3) TESTING OF CONTROL SYSTEM DELAY

The delay test was carried out by referring to RTC. The delay value was obtained by calculating the difference between the time when the temperature was set on the server and when the gateway reached the greenhouse temperature threshold. Delay testing was carried out to evaluate the time taken by the

TABLE I
TESTING RESULT OF MONITORING SYSTEM DELAY

Time (Western Indonesian Time, WIB)	Amount of Data	Average Delay (s) (Gateway – Server)
00.00-00.01	1,187	1.7
01.00-02.00	1,680	1.6
02.00-03.00	1,221	1.7
03.00-04.00	1,486	1.8
04.00-05.00	1,532	1.8
05.00-06.00	1,680	1.9
06.00-07.00	3,214	1.8
07.00-08.00	1,680	1.9
08.00-09.00	1,632	2
09.00-10.00	1,641	1.8
10.00-11.00	1,681	2.1
11.00-12.00	1,618	1.8
12.00-13.00	322	1.7
13.00-14.00	613	1.9
14.00-15.00	1,667	1.9
15.00-16.00	1,622	2.1
16.00-17.00	1,682	2.1
17.00-18.00	1,627	2
18.00-19.00	1,680	1.9
19.00-20.00	1,629	2
20.00-21.00	1,682	2.3
21.00-22.00	1,512	2.3
22.00-23.00	1,577	2.1
23.00-00.00	1,681	1.8
Average Delay		1.9

tool to transmit and receive data, by referring to the RSSI value [20]. It was performed when setting the threshold value, which was then sent to the server. The 1999–2006 ETSI standard was used as a reference for system evaluation.

III. RESULTS AND DISCUSSION

A. TEST RESULTS OF MONITORING SYSTEM DELAY

Delay testing on the gateway-server monitoring system was conducted to determine the time difference between when the gateway transmitted the data and when the server received the data. This test was carried out by taking data once an hour for 24 hours.

Table I shows the results of the gateway-server delay test. From the 24-hour test, the average delay was 1.9 s. This value falls within the category of acceptable delay, as determined by ETSI in 1999. The following command was employed to determine the amount of data and the average delay on the server: SELECT AVG((SELECT TIMEDIFF(`server_time`, `waktu`) WHERE `server_time` BETWEEN ‘2022-03-25 17:00:00’ AND ‘2022-03-25 18:00:00’)) AS ‘rata-rata’, COUNT(`node`) AS ‘jumlah’ FROM `parameter_greenhouse` WHERE `server_time` BETWEEN ‘2022-03-25 17:00:00’ AND ‘2022-03-25 18:00:00’. The writing of the command was adjusted to the day and time required.

B. TEST RESULTS OF DATA LOSS OF THE MONITORING SYSTEM

Data loss testing was carried out to determine the percentage of data received by the server with data sent by the gateway. The test was conducted for 24 hours, with data collection done once an hour. Table II shows the results of data loss gateway-server testing. The amount of data sent from the gateway was calculated manually via a node that sent one data per 30 s to the gateway. The data obtained were the data sent by the node to the gateway and sent directly to the server.

TABLE II
TESTING RESULTS OF DATA LOSS MONITORING SYSTEM

Time (Western Indonesian Time, WIB)	Transmitted Data (Gateway)	Received Data (Gateway – Server)	Data Loss (%)
00.00-00.01	1,680	1,187	29
01.00-02.00	1,680	1,680	0
02.00-03.00	1,680	1,221	27
03.00-04.00	1,680	1,486	11
04.00-05.00	1,680	1,532	8
05.00-06.00	1,680	1,680	0
06.00-07.00	1,680	1,534	8
07.00-08.00	1,680	1,680	0
08.00-09.00	1,680	1,632	2
09.00-10.00	1,680	1,641	2
10.00-11.00	1,680	1,681	0
11.00-12.00	1,680	1,618	3
12.00-13.00	1,680	322	80
13.00-14.00	1,680	613	63
14.00-15.00	1,680	1,667	0.7
15.00-16.00	1,680	1,622	1
16.00-17.00	1,680	1,682	0
17.00-18.00	1,680	1,627	3
18.00-19.00	1,680	1,680	0
19.00-20.00	1,680	1,629	3
20.00-21.00	1,680	1,682	0
21.00-22.00	1,680	1,512	10
22.00-23.00	1,680	1,577	6
23.00-00.00	1,680	1,681	0
Average Delay			10.6

With the rate of one data transmission every 30 s and a maximum of fourteen nodes, 1,680 data were transmitted per hour. The amount of data received on the server may be known through omahiot.net in the parameter table_greenhouse. Using the SELECT COUNT(‘node’) command FROM `parameter_greenhouse` WHERE `server_time’ BETWEEN ‘2022-03-25 17:00:00’ AND ‘2022-03-25 18:00:00’, the amount of data received appeared, which was 1,680 data. The writing of the above command was adjusted to the time and date needed.

C. TEST RESULTS OF SERVER-GATEWAY CONTROL SYSTEM DELAY

Delay testing of the server-gateway control system was carried out to determine the time difference when the farmer set the threshold limit on the server through the application with the time when the gateway received the threshold data from the greenhouse. Delays were calculated manually. The gateway panel shows the maximum temperature for activation and the minimum temperature for deactivation.

The largest server-gateway delay was 17 s, which occurred when the threshold limit was 17 °C for the lowest temperature to 32 °C for the highest temperature with the ON condition and the SHT 30 sensor reading was 24 °C and the RSSI value was 17. In addition, the largest server-gateway delay, which was 17 s, also occurred when the threshold limit was 28 °C (lowest temperature) to 29 °C (highest temperature) with an OFF condition and a SHT 30 sensor reading of 24 °C and an RSSI

TABLE III
SERVER-GATEWAY CONTROL SYSTEM DELAY TESTING RESULT

No	Sensor Data (°C)	Threshold (°C)		Delay Server–Gateway (s)	RSSI	Condition (ON/OFF)
		Min	*Max*			
1	24	16	18	1	14	ON
2	24	16	20	14	13	ON
3	24	17	31	2	17	ON
4	24	17	32	17	17	ON
5	24	18	26	3	17	ON
6	24	18	30	5	15	ON
7	24	20	21	2	16	ON
8	24	20	22	2	14	ON
9	24	20	24	14	16	ON
10	24	22	24	12	16	ON
11	24	24	26	1	17	OFF
12	24	24	27	16	13	OFF
13	24	25	26	2	16	OFF
14	24	25	30	2	17	OFF
15	24	26	28	6	17	OFF
16	24	27	30	2	14	OFF
17	24	28	29	17	17	OFF
18	24	28	31	2	17	OFF
19	24	29	30	6	15	OFF
20	24	30	31	13	13	OFF
21	24	30	32	11	17	OFF
Average of overall delay (s)				7.1		

value of 17. Meanwhile, the lowest server-gateway delay was 1 s, which occurred when the threshold limit was 16 °C (lowest temperature) to 18 °C (highest temperature) with ON conditions and the SHT 30 sensor reading was 24 °C with an RSSI value of 14. The lowest server-gateway delay of 1 s also occurred when the threshold limit was 24 °C (lowest temperature) to 26 °C (highest temperature) with an OFF condition and a SHT sensor reading of 30 of 24 °C and an RSSI value of 17.

Table III shows that the control system delay when farmers put a threshold limit on the server through the website to the gateway has an average of 7.1 s. Based on the ETSI 1999 standards, the average delay value falls into the category of bad delay. The control process takes a long time because the GET process through the GPRS network is not easy to connect to the internet. In addition, the delay was also influenced by the length of reading other sensor data programs.

D. DISCUSSION

The objective of the conducted research is to facilitate the work of agricultural workers. The existence of technological intervention in agriculture is enough to help ease the work of farmers. In this study, the results indicate that greenhouse monitoring and control experienced an average data loss of 10.6% in the gateway-server monitoring. Additionally, the average delay in gateway-server monitoring was found to be 1.9 s, while the average delay in server-gateway control was 7.1 s. Additionally, the factors that contribute to the success of the harvest, such as temperature, humidity, and light intensity, are taken into account. The optimal temperature for hydroponic cultivation methods is typically between 25 °C–28 °C, with the recommended light intensity falling within the range of 2,000–3,000 fc. The results obtained suggest that the monitoring and control measures have significant advantages for the greenhouse and its crop yield.

IV. CONCLUSION

Based on the research that has been done, the following conclusions can be drawn. The IoT-based greenhouse parameter monitoring, and control system has been successfully developed and is running well. The results of QoS testing are as follows. The average data loss of gateway-server monitoring was 10.6%, the average delay of gateway-server monitoring was 1.9 s, and the average delay of server-gateway control was 7.1 s. When the greenhouse temperature parameter is less than the specified maximum threshold, the system will turn on the drum fan until the temperature reaches the minimum value at the threshold limit.

CONFLICTS OF INTEREST

The author team stated that the article entitled “Monitoring and Controlling of IoT-Based Greenhouse Parameters With the MQTT Protocol” was written free from conflicts of interest.

AUTHORS’ CONTRIBUTIONS

Conceptualization, Eni Dwi Wardihani and Eka Ulia Sari; methodology, Eni Dwi Wardihani and Eka Ulia Sari; software, Helmy; validation, Ari Sriyanto Nugroho; data curation, Yusnan Badruzzaman; original drafting, Eka Ulia Sari; reviewing and editing, Arif Nursyahid; visualization, Thomas Agung Setyawan; funding acquisition, Media Fitri Isma Nugraha.

ACKNOWLEDGMENT

The National Research and Innovation Agency (Badan Riset dan Inovasi Nasional, BRIN) and the Indonesia Endowment Fund for Education are acknowledged for their generous support of this research under the Research and Innovation for Advanced Indonesia (RIIM) scheme.

REFERENCES

[1] Amam and S. Rusdiana, “Pertanian Indonesia dalam menghadapi persaingan pasar bebas,” *J. Agriovet*, vol. 4, no. 1, pp. 37–68, Oct. 2021, doi: 10.51158/agriovet.v4i1.506.

[2] A.R. Salasa, “Paradigma dan dimensi strategi ketahanan pangan Indonesia,” *Jejaring Admin. Publik*, vol. 13, no. 1, pp. 35–48, Sep. 2021, doi: 10.20473/jap.v13i1.29357.

[3] A. Musthafa, S.N. Utama, and T. Harmini, “Sistem kontrol suhu ruangan dan penyiraman tanaman bawang merah pada greenhouse dengan smartphone,” *Multitek Indones. J. Ilm.*, vol. 12, no. 2, pp. 95–103, Dec. 2018, doi: 10.24269/mtkind.v12i2.1254.

[4] N.D. Setiawan, “Otomasi pencampur nutrisi hidroponik sistem NTF (nutrient film technique) berbasis Arduino Mega 2560,” *J. Tek. Inform. Unika St. Thomas (JTIUST)*, vol. 3, no. 2, pp. 78–82, Dec. 2018, doi: 10.17605/jti.v3i2.292.

[5] Helmy *et al.*, “Pemantauan dan pengendalian kepekatan larutan nutrisi hidroponik berbasis jaringan sensor nirkabel,” *J. Nas. Tek. Elekt. Teknol. Inf.*, vol. 7, no. 4, pp. 391–396, Nov. 2018, doi: 10.22146/jnteti.v7i4.456.

[6] L. Rahmawati, H. Iswahyudi, and B. Alexander, “Penerapan hidroponik sistem nutrient film technique (NFT) di Politeknik Hasnur,” *Agrisains, J. Budid. Tanam. Perkeb.*, vol. 6, no. 1, pp. 8–12, Jun. 2020, doi: 10.46365/agrs.v6i01.371.

[7] M.A.K. Parikesit *et al.*, “Otomatisasi sistem irigasi dan pemberian kadar nutrisi berdasarkan nilai total dissolve solid (TDS) pada hidroponik nutrient film technique (NFT),” *Widya Tek.*, vol. 17, no. 2, pp. 70–78, Nov. 2018, doi: 10.33508/wt.v17i2.1964.

[8] A.D. Purwanto, F. Supegina, and T.M. Kadarina, “Sistem kontrol dan monitor suplai nutrisi hidroponik sistem deep flow technique (DFT) berbasis Arduino NodeMCU dan aplikasi Android,” *J. Teknol. Elekt.*, vol. 10, no. 3, pp. 152–158, Sep. 2019, doi: 10.22441/jte.v10i3.002.

[9] M.A.J. Hidayat and A.Z. Amrullah, “Sistem kontrol dan monitoring tanaman hidroponik berbasis Internet of things (IoT) menggunakan

NodeMCU ESP32," *J. Saintekom, Sains Teknol. Komput. Manaje.*, vol. 12, no. 1, pp. 23–32, Mar. 2022, doi: 10.33020/saintekom.v12i1.223.

[10] William, H. Suharto, and H. Tanudjaja, "Sistem pemantauan dan pengendalian parameter lingkungan pertumbuhan pada tanaman hidroponik," *TESLA, J. Tek. Elekt.*, vol. 18, no. 2, pp. 188–207, Oct. 2016, doi: 10.24912/tesla.v18i2.305.

[11] M.J.D. Firdausyah, P.W. Rusimamto, B. Suprianto, and Endryansyah, "Sistem pengendali suhu air nutrisi pada hidroponik NFT (nutrient film technique) berbasis PID controller," *J. Tek. Elekt.*, vol. 11, no. 1, pp. 117–125, Jan. 2022, doi: 10.26740/jte.v11n1.p117-125.

[12] R. Susana, F. Hadiatna, and A. Gusmantini, "Sistem multihop jaringan sensor nirkabel pada media transmisi Wi-Fi," *Elkomika, J. Tek. Energi Elekt. Tek. Telekomun. Tek. Elektron.*, vol. 9, no. 1, pp. 232–248, Jan. 2021, doi: 10.26760/elkomika.v9i1.232.

[13] U. Syafiqoh, Sunardi, and A. Yudhana, "Pengembangan wireless sensor network berbasis internet of things untuk sistem pemantauan kualitas air dan tanah pertanian," *J. Inform., J. Pengemb. IT*, vol. 3, no. 2, pp. 285–289, May 2018, doi: 10.30591/jpit.v3i2.878.

[14] T.M. Bandara, W. Mudiyanselage, and M. Raza, "Smart farm and monitoring system for measuring the environmental condition using wireless sensor network - IoT technology in farming," *2020 5th Int. Conf. Innov. Technol. Intell. Syst. Ind. Appl. (CITISIA)*, 2020, pp. 1–7, doi: 10.1109/CITISIA50690.2020.9371830.

[15] A. Omairi and Z.H. Ismail, "Low power wireless temperature and humidity sensing based on CM5000 node and SHT11 sensor," *2016 IEEE Int. Conf. Underw. Syst. Technol., Theory Appl. (USYS)*, 2016, pp. 183–187, doi: 10.1109/USYS.2016.7893907.

[16] I.G.S. Sudaryana, "Pemanfaatan relai tunda waktu dan kontaktor pada panel hubung bagi (PHB) untuk praktek penghasutan starting motor star delta," *J. Pendidik. Teknol. Kejuru.*, vol. 12, no. 2, pp. 97–108, Jul. 2015, doi: 10.23887/jptk-undiksha.v12i2.6478.

[17] B. Smith, *Beginning JSON*. Berkeley, CA, USA: Apress Berkeley, 2015.

[18] *Evaluation of Measurement Data — Guide to the Expression of Uncertainty in Measurement*, JCGM 100:2008, Sep. 2008. [Online]. Available: https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6

[19] "Telecommunications and Internet Protocol Harmonization Over Networks (TIPHON); General aspects of Quality of Service (QoS)," ETSI, Valbonne, France, TR 101 329 V2.1.1 (1999-06), 1999. [Online]. Available: https://www.etsi.org/deliver/etsi_tr/101300_101399/101329/02.01.01_60/tr_101329v020101p.pdf

[20] J. Bardwell. *Converting Signal Strength Percentage to dBm Values WildPackets*. (2002). [Online]. Available: https://d2cpnw0u24fjm4.cloudfront.net/wp-content/uploads/Converting_Signal_Strength.pdf